Toronto Metropolitan University

Department of Aerospace Engineering
Faculty of Engineering & Architectural Science

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LAB 1 WORKSHEET

Warm-Up

1. Write down the equation (symbolically) for the 40th output for a 3rd order (4-point) moving average filter. Use the equation in section 2.5.

$$y(n) = \frac{1}{M}\sum_{k=0}^{M-1} x\cdot(n-k) \;\rightarrow\; y(40) = \frac{1}{4}\sum_{k=0}^{4-1} x\cdot(40-k)$$

$$y(40) = \frac{1}{4}x\cdot(40+39+38+37)$$

$$y(40) = \frac{77}{2}x$$

2. Determine the smallest voltage that can be resolved by this ADC? The full-scale voltage range is 20V (bipolar ±10V).

$$V_{min} = \frac{20V}{2^{14-1}}$$

$$V_{min} = 0.002441406\,V = 2.44\,mV$$

Part A

3. Look at the signals in the scopes and write down your observations with respect to the impulse response of all the filters. Do the filters behave as expected?

Yes they do. The unfiltered signal behaves erratically and the 11 point can be seen as the most reliable and representative signal when compared to the other signals.

4. Compute the time delay for the two moving average filters. Use the "Scope all" graphs to verify your results. Are the results the same? What is the delay of the 2nd order Butterworth filter?

	Calculation:	Observed
Equation:	$t_d = \frac{n-1}{2\cdot F_s}$	
5 Point :	$\frac{4-1}{2\cdot 100} = \frac{9}{200} = 0.015\,s = 15\,ms$	$20\,ms$
11 Point:	$\frac{10-1}{2\cdot 100} = \frac{9}{200} = 0.045\,s = 45\,ms$	$50\,ms$

It was observed that the results of the calculated time delay for both 5 point and 11 point filters was similar to the time delays that were observed, with there only being a 5 ms difference for both filters. The delay of the 2nd order Butterworth filter was 20 ms.

5. Look at the signals in the scopes and write down your observations with respect to the impulse response of all the filters. Do the filters behave as expected?

Yes the signals behave as expected as the data looks similar to Fig. 1.5 in the lab manual. Furthermore, the signals become less noisy as the order increases and the sinusoidal wave becomes more clear. The 2nd order Butterworth filter is the most noisy signal compared to the 5 point and 11 point signals.

6. Set the frequency of the sine wave equal to 4*pi (2Hz) and observe the new result. Repeat for a frequency of 8*pi (4Hz). What is happening to the signal? What does this tell us about the limits of the MA filter?

As the frequency increases the data becomes less reliable as it becomes more compressed, while the number of datapoints remains the same. The signals become more jagged and overall cause a noisier signal.

Part B-1

7. What do you see?

The 'Scope - All' block shows the unfiltered tachometer signal, the encoder speed output, and the filtered signals. The unfiltered signal is the noisiest, with rapid changes in amplitude. The encoder speed output is less noisy but still shows some variation. The second-order and fourth-order Butterworth filters produce smoother signals with fewer fluctuations. The tenth-order filter generates the smoothest waveform with the least amount of noise, showing minimal changes in amplitude.

Also, how does the accuracy of the tachometer compare encoder speed values?

The unfiltered tachometer values are less accurate than the encoder speed values because the unfiltered signal shows larger changes in amplitude between points. Also, the encoder values are based on estimations, while the tachometer values come directly from raw data obtained from the DC motor, which explains why the encoder is more accurate.

8. Assuming the sensor is operating within specifications, what factors could be contributing to the variation in the signal?

The tachometer's accuracy can be affected by environmental factors such as friction, resistance, and vibrations from the DC motor. In contrast, the encoder's performance may suffer from high temperatures and prolonged moisture exposure.

When comparing the two instruments, the tachometer directly measures the rotation speed of an object, while the encoder measures position in relation to rotational speed. The tachometer provides immediate data, whereas the encoder uses a feedback loop to make adjustments while the system operates, enhancing the precision and accuracy of its output compared to the tachometer.

9. Using the Nyquist theorem in Section 2.4.4, what is the maximum frequency that our system sampling rate allows us to capture from any sampled signal?

System Sampling Rate: **200 Hz** Maximum Frequency: **100 Hz**

$$\frac{200\,Hz}{2} = 100\,Hz$$

Part B-2

10. Record your observations with respect to the relative performance of the filters. For this application, which of the filters has the best performance if time delay is NOT an issue? Why?

The unfiltered signal behaves erratically showing a significant amount of noise. The 5 point filter reduces some of the noise while adding a partial time delay, the 51 point filter introduces significant time delay though it creates a smoother signal with far fewer fluctuations. The Butterworth filter significantly reduces the noise while adding minimal time delay, providing an optimal signal considering time delay. If time delay is not an issue the optimal filter would be the 51 point filter which provides the least noisy signal.

7. Print a copy of the 'Scope - All' figure. Make sure to label the individual signals on your graph. Zoom In to get a clearer picture.

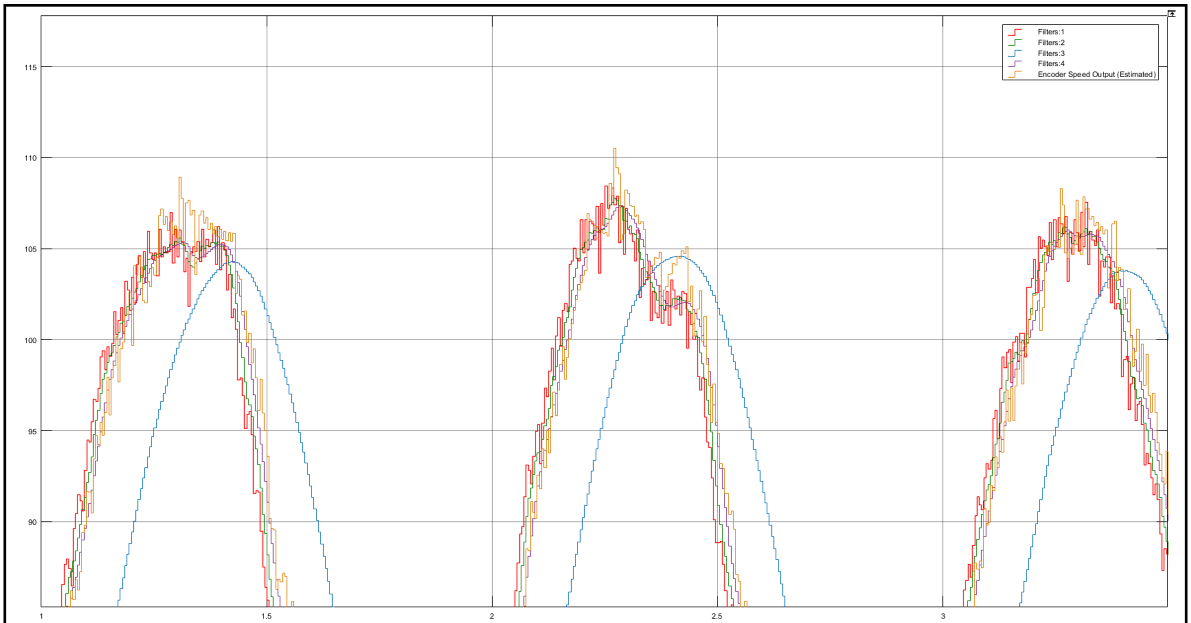

Figure 1: *Signal Output - Zoomed Out*

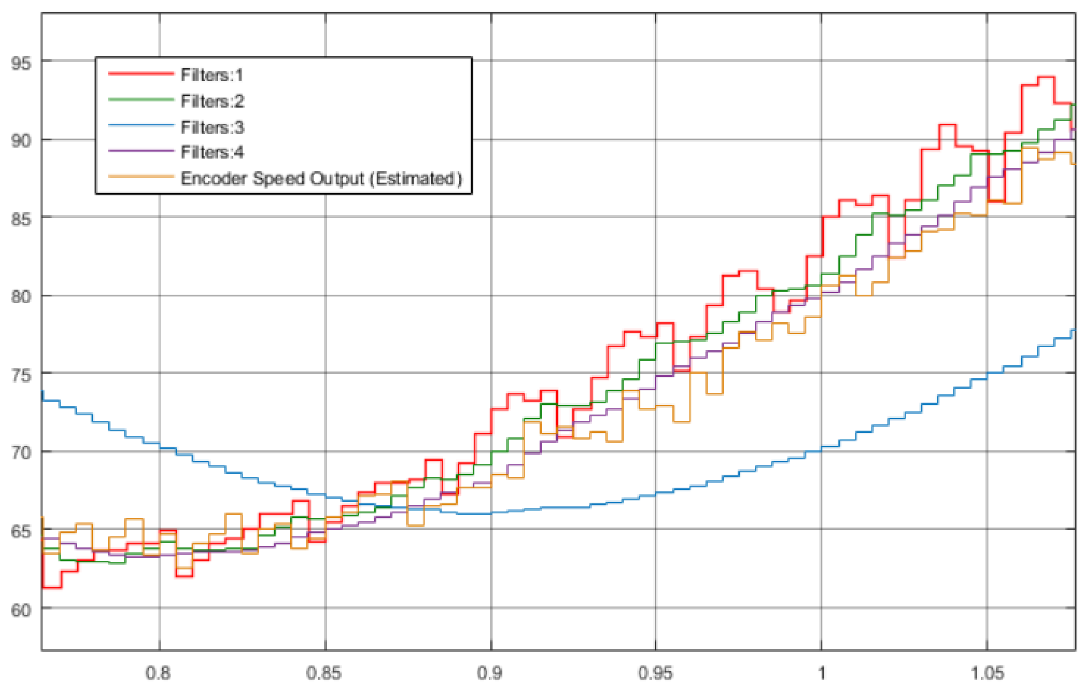

Figure 2: *Signal Output - Zoomed In*

References

[1] Chan, C., & Liu, Dr. G. (2024). AER 715 Avionics and Systems Laboratory 1: Introduction to Digital Signal Processing. Login - Toronto Metropolitan University Central Authentication Service. https://courses.torontomu.ca/d2l/le/content/910158/viewContent/5832927/View [Accessed: Sep. 15, 2024].